Using BIM for Smarter and Safer Scaffolding and Formwork Construction: A Preliminary Methodology

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Abstract

The goal of this research project is to develop specific BIM objects for temporary construction activities which are fully integrated with object design, construction efficiency and safety parameters. Specifically, the project will deliver modularised electronic scaffolding and formwork objects that will allow designers to easily incorporate them into BIM models to facilitate smarter and safer infrastructure and building construction.

This research first identified that there is currently a distinct lack of BIM objects for temporary construction works resulting in productivity loss during design and construction, and opportunities for improved safety practices with the design of scaffolding and formwork. This is particularly relevant in Australia, given the “harmonisation” of OHS legislation across all states and territories from 1 January 2012, meaning that enhancements to Queensland practices can have direct application across Australia.

Thus, in conjunction with government and industry partners in Queensland, Australia, the research team developed a strategic three-phase research and industry skills development methodology: (1) the preliminary review phase on industrial scaffolding and formwork practices and BIM implementation; (2) the BIM object development phase with specific safety and productivity functions; and (3) the Queensland-wide workshop phase for product dissemination and training.

This paper discusses background review findings, details of the developed methodology, and expected research outcomes and their contributions to the Australian construction industry.

Keywords

Construction safety, BIM for safety, scaffolding and formwork construction, BIM for temporary construction

INTRODUCTION

According to Safe Work Australia (2012), there were a total of 14,760 serious workers' compensation claims issued in the Australian construction industry in 2007-08; scaffolding and formwork-related claims accounted for 3% of all claims (410 claims). Queensland was responsible for about 32% of these scaffolding and formwork claims (130 claims) (Figure 1); costing $1,027,000, as calculated using the median payment in Queensland of $7,900. In response to an increase in scaffolding and formwork incidents, Workplace Health and Safety Queensland (WHSQ) conducted campaigns that focused on industry compliance with standards and codes, most recently in 2007-10 (WHSQ 2008; WHSQ 2010). Audit checklists developed by WHSQ in conjunction with industry stakeholders were used to assess the compliance of 73 formwork sites and 246 scaffolding sites in Queensland. The audit results showed that scaffolding compliance was low with 59% and indicated 18% noncompliance rates for formwork safety plans and work method statements.

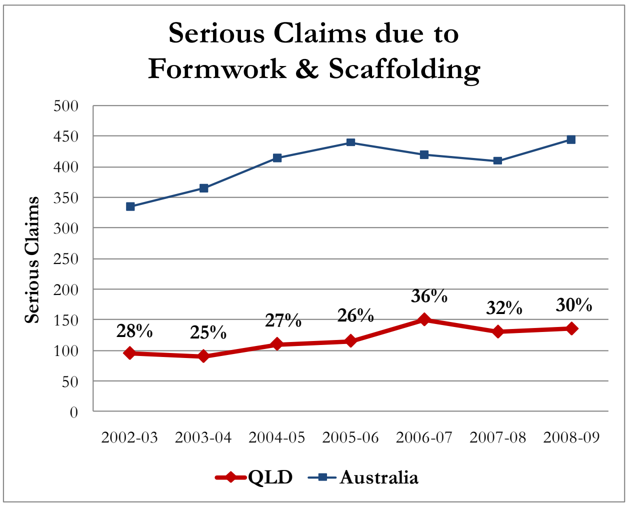

Figure 1 Serious injury claims due to formwork and scaffolding in Australia and Queensland

To prevent injuries and save the lives of construction workers, there has been considerable interest in improving worksite safety through safer design and work method statements using Building Information Modelling (BIM). BIM provides 3D electronic information about the final form of facilities such as infrastructure and buildings. Through integrating such 3D information, BIM can represent all structural components such as beams, columns, walls and floors. BIM can also encapsulate information other than physical properties such as construction sequencing and safety information. An integrated element or component is called a BIM object. To improve construction safety, some researchers investigated the application potential of BIM for safer construction design (e.g. clash detection between sequential activities) and safety planning (e.g. 3D design review for construction risk analysis and mitigation) (Furst 2009; Ku and Mills

2010; Lew and Lentz 2010; Puerto and Clevenger 2010; Zhou *et al*. 2011). Other researchers introduced safety-integrated 5D (3D design with schedule and safety information) models that linked 3D safety features with the construction plan (Sulankivi *et al*. 2009; Benjaoran and Bhokha 2010; Ciribini *et al*. 2011). For instance, Sulankivi *et al*. (2009) incorporated a fence installation process into the precast unit construction schedule using BIM for fall protection.

As Sulankivi *et al.* (2009) discussed, BIM objects can be applied to the temporary works required for construction. However, the authors have identified that there is currently a distinct lack of parametric BIM objects for temporary construction works and safety standards and regulations have not been seriously considered for design of temporary construction objects. Thus, the research team has determined the potential to significantly reduce the risk of workplace accidents and improve productivity through application of BIM to temporary works – particularly, the industry-identified high risk components of scaffolding and formwork.

The research presented in this paper aims to develop specific BIM objects for temporary construction works which are fully integrated; including object design, construction efficiency and safety parameters. Specifically, this project will deliver modularised scaffolding and formwork objects that will allow designers to easily incorporate them into BIM models to facilitate smarter and safer infrastructure and building construction. This is an on-going research project and this paper presents background review findings, details of the developed preliminary methodology, and expected research outcomes and their contributions to the Australian construction industry.

LITERATURE REVIEW

Background Review on BIM Practices for Construction Safety

As briefly discussed in the Introduction, many research studies have employed BIM and expanded its benefits for construction safety. Table 1 summarises the reviewed BIM practices applied for construction safety.

Table 1 BIM for construction safety

No	BIM Application	Hadipriono and Barsoum 2002	Lee et al. 2007	Strafaci 2008	Furst 2009	Ruppel and Abolghasemzadeh 2009	Scia Scaffolding 2009	Sulankivi et al. 2009	Benjaoran and Bhokha 2010	Hu et al. 2010	Ku and Mills 2010	Lew and Lentz 2010	Liu et al. 2010	Meadati et al. 2010	Puerto and Clevenger 2010	Sattineni 2010	Ciribini et al. 2011	Giretti et al. 2011	Ku and Mahabaleshwarkar 2011	Leith and Akinci 2011	Zhou et al. 2011
1	Design for safety			•	•						•	•									•
2	Safety-integrated 4D model							•	•								•				
3	Structural safety analysis and constructability		•	•			•			•			•	•							
4	On-site design inspection																•		•		
5	On-site safety monitoring															•		•			
6	Safety planning														•						
7	Safer site layout planning							•									•				
8	Safety training	•																	•		
9	Facility management and emergency responses					•									•					•	

First, some researchers investigated how to design for safety improvement (No. 1 in Table 1). Strafaci (2008) emphasised that BIM has the ability to use the information to design, analyse and simulate road construction. This study integrated visualisation techniques and sight distance simulation into the design process and assisted the road designers to evaluate if the road geometry met safety requirements. Furst (2009) suggested that different design standards were required to be applied to different construction tasks for safety enhancement and determined that owners, designers, contractors and safety professionals must cooperate to achieve a safer work environment. Ku and Mills (2010) reviewed existing design-for-safety tools and determined their constraints. They then explored BIM's capabilities to support addressing the existing problems and suggested to incorporate BIM for hazard recognition and design optimisation. Lew and Lents (2010) introduced application examples of designing for safety such as structural design layout analysis to reduce exposure to falling accidents and design innovation for more durable skylights with metal coverings to prevent falls through them. Zhou *et al.* (2011) developed a virtual reality tool that enhanced the interaction between builders and designers and assisted designers to evaluate the site environment and to design safer construction processes required to the given environment.

Second, some researchers integrated safety elements into the design for safer construction (No. 2 in Table 1). Sulankivi *et al.* (2009) discussed the demand for including the installation process of temporary safety structures into the BIM model for better understanding of the progress of the project, future work schedule, and related safety processes. For example, they incorporated a fence installation process into the precast unit construction schedule using BIM for fall protection. Benjaoran and Bhokha (2010) incorporated safety elements with the construction process during the design phase using 4D CAD models in order to detect work-related hazards and suggest necessary safety activities for risk mitigation. Ciribini *et al*. (2011) introduced a preliminary concept of a BIM-based safety measurement system linked with technical design standards, contracts and safety measures.

Additionally, BIM has also been used for structural safety and constructability analysis during the design phase (No. 3 in Table 1). Lee *et al*. (2007) developed a preliminary formwork layout planning system and determined formwork layout meeting the design requirements such as work space limitations or exterior and interior building shapes. The system considered cost and constructability factors for layout selection. Strafaci (2008) suggested road engineers design for constructability, not only for code compliance, using BIM to prevent change orders, RFIs and thus reduce expected project delays. Scia Scaffolding (2009) created 3D scaffolding CAD models incorporated with automated code checking and stability analysis features. Hu *et al*. (2010) developed a 4D structural safety analysis model and applied the model to evaluate structural conditions of the National Stadium of the 2008 Beijing Olympic Games during construction phases. Liu *et al*. (2010) similarly introduced a BIM-based durability evaluation system for concrete structures. Lastly, Meadati *et al*. (2010) developed a concrete formwork repository using BIM and discussed its application potential on structural health monitoring, material quantity takeoff, design optimisation, design for constructability and automated drawing production.

In addition to incorporating BIM to the design phase, some researchers investigated how to use BIM in the field to improve on-site construction safety. Ciribini *et al*. (2011) and Ku and Mahabaleshwarkar (2011) introduced BIM's benefits for on-site design compliance checking when integrated with state-of-the-art technologies (No. 4 in Table 1). Ciribini *et al*. (2011) emphasised the importance of real-time work progress monitoring and discussed that comparison between as-planned BIM designs and as-built 3D information captured by the laser scanning technology supports proactive on-site safety condition monitoring by detecting missing safety components such as guardrails or safety nets surrounding working areas. Ku and Mahabaleshwarkar (2011) developed an interactive software environment between users and virtual construction environments called

Building Interactive Modelling. They presented its capabilities for collaborative information and knowledge sharing and proper design interpretation and compliance checking on a construction site. Moreover, some research studies investigated on-site safety monitoring and assessment methods by merging BIM with real-time tracking technologies (No. 5 in Table 1). Sattineni (2010) prepared safety-integrated BIM models, for examples 3D building models with dangerous area information, and then suggested to track the movement of construction workers in real time using RFID and wireless tags for the safety supervision purpose. Similarly, Giretti *et al*. (2011) developed a real-time safety monitoring system by applying ultra-wide band based technologies. The system enabled real-time position tracking of workers and prevented non-authorised access to dangerous zones.

BIM has also been used to enhance safety planning and education. Puerto and Clevenger (2010) exemplified BIM applications to increase worker safety by investigating potential "pinch-points" ahead of actual material installation through 4D design review during the project planning phase (No. 6 in Table 1). They discussed that BIM fundamentally improved communication among diverse project team members so that they were able to evaluate different construction options to optimise safety of workers and the general public. BIM also provides benefits for safer site layout planning (No. 7 in Table 1). Sulankivi *et al*. (2009) claimed temporary equipment and spaces such as office containers, material storage or heavy machinery had not offered 3D descriptions and created visualisation models to analyse risk zones related to crane operations and to inform the safest site walkways for workers at each stage of construction. Ciribini *et al*. (2011) proposed a BIM-based space breakdown structure that identified different types of construction spaces including building component spaces, site layout spaces, worker working spaces, equipment spaces and material spaces and evaluated safety risk levels of the restricted working areas and shared spaces by measuring space requirements and space conflicts.

Some other researchers have also employed BIM for staff safety training (No. 8 in Table 1). Hadipriono and Barsoum (2002) introduced an interactive training model for form scaffolding safety training. They developed two safety training modules; one for the scaffolding erection and the other for the inspection of existing structures. The trainees were able to not only follow the safe form scaffolding erection steps from the virtual working environment with 3D models but also audit hazardous conditions in an existing scaffolding structures. Similarly, Ku and Mahabaleshwarkar (2011) developed interactive virtual 3D models with the Second Life platform for scaffolding safety training and tower crane operation training. The scaffolding safety training module was designed similar to Hadipriono and Barsoum (2002)'s model. The crane operation training module determined collision-free and optimal-operational paths for erecting structural elements while enhancing construction safety and work productivity.

Lastly, some research studies investigated BIM's benefits for safer facility management and emergency responses (No. 9 in Table 1). Ruppel and Abolghasemzadeh (2009) conducted BIM-based computer simulation to evaluate different fire safety scenarios and optimise evacuation processes in the event of building fire. Under the realistic virtual environment in BIM, they were able to assess fire sources and diffusion routes and time, geometrical building structures, obstructions and openings and locations of fire protective equipment, such as sprinklers, to develop safe evacuation plans. Leite and Akinci (2011) also evaluated vulnerability in facilities using BIM during an emergency event by triggering a failure in a building system. They evaluated the case with multiple failures of building systems during a flood event followed by power outage. Puerto and Clevenger (2010) focused BIM's application potential on facility management and introduced a case study of using BIM to support documenting electronic operation and maintenance processes and communicating the proper sequence of valve shut-downs for facility managers. By embedding construction photographs into BIM, facility managers were also able to locate hidden electrical and plumbing components during maintenance and repairs.

Background Review Findings

Despite the advancements, there are still major limitations with significant opportunity for improvement in BIM-based safety studies. The research team have identified areas of temporary construction works where BIM objects have the potential to significantly lessen the danger of workplace accidents in building and infrastructure construction. Specific areas where further knowledge and safety processes are necessary are in scaffolding and formwork. Although some researchers have developed 3D formwork and scaffolding structures, they are not parametric BIM objects that can be easily incorporated into other BIM construction elements and they do not seriously consider safety standards and regulations for design.

PROPOSED METHODOLOGY

The goal of this research project is to develop specific BIM objects for temporary construction activities which are fully integrated with object design, construction efficiency, and safety parameters. Specifically, the project will deliver modularised electronic scaffolding and formwork objects that will allow designers to easily incorporate them into BIM models to facilitate smarter and safer infrastructure and building construction. This is particularly relevant in Australia, given the “harmonisation” of Occupational Health and Safety legislation across all states and territories from 1 January 2012, meaning that enhancements to Queensland practices will have direct application across Australia.

The development and use of the proposed scaffolding and formwork BIM objects will: (1) enable design in accordance with safety requirements; (2) incorporate design codes; (3) design for constructability in 4D (3D with schedule); (4) provide visualisation of the installation procedure, design and installation options, and give working condition analyses, such as limited clearance with the surrounding environment; (5) enable structural safety analysis; (6) highlight opportunities for design innovation; and (7) provide BIM checklists for routine on-site inspections that would benefit practical safety assessment on construction sites. Figure 2 illustrates a conceptual research design of the project. The developed BIM objects would lead design-oriented safety planning and provide onsite practitioners with 4D design and relevant safety information for productivity improvement and safety compliance.

Thus, in conjunction with government and industry partners in Queensland, Australia, the research team developed a strategic three-phase research methodology. During the preliminary phase, the research team will review the safety literature, industrial scaffolding and formwork practices, BIM technology and the integration of BIM into management practice. The team will determine the conceptual BIM object types and structures that are required. One-on-one meetings and a workshop will be conducted with industry collaborators to present these preliminary findings for feedback, and to further develop the BIM object requirements. The research team aims to identify key scaffolding and formwork systems for introduction into the BIM framework. They have tentatively identified: wedgelock scaffold for edge protection, wedgelock scaffold for formwork support, formwork frame towers and accessories, system soffit formwork, wall formwork, tableforms, cuplock scaffold, ringlock scaffold, formwork screens, jumpform and coreform, and formwork hoists. Experts in the construction industry, including scaffolding and formwork designers, contractors, project managers, safety managers will be consulted to identify critical factors and issues on design, constructability and innovative elements.

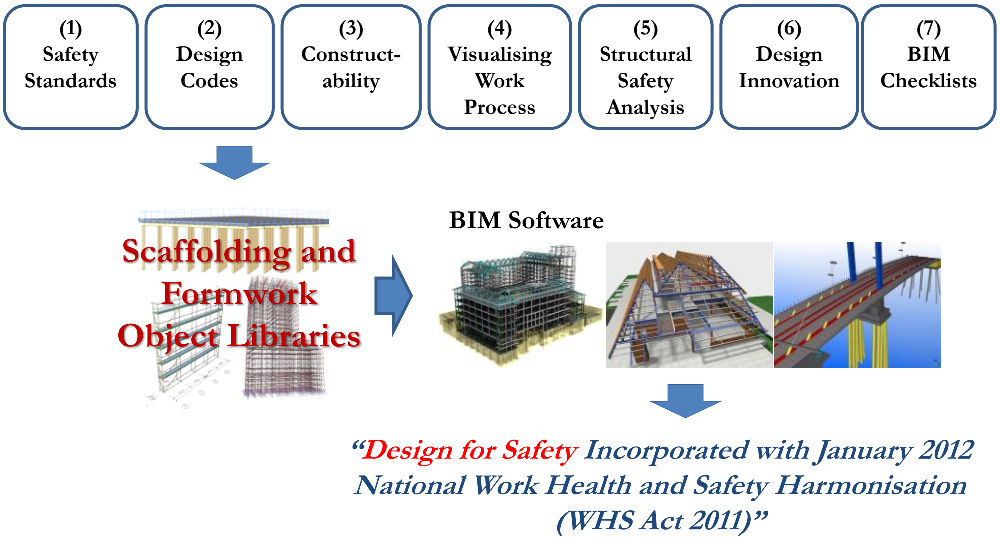

Figure 2 Conceptual research design

During the BIM object development phase, the research team will design 3D BIM scaffolding and formwork objects for incorporation with safety features and constructability elements into the BIM system. The team will develop pilot BIM objects for the key scaffolding and formwork systems. Safety features and constructability issues will be embedded into 3D scaffolding and formwork models. These objects will be designed to be compatible with a variety of existing BIM software systems and will be available in open source format for public use: designers will be able to readily access them from the project website.

Once pilot BIM objects are ready for use, the research team will identify two construction sites for performance assessment; one building construction project and one infrastructure project will be selected. These projects will include one site in a Queensland city and another located in a regional area. These field tests will be important to assess the usability and practicality of the developed models. The designers and construction contractors who work on these evaluation projects will use the new scaffolding and formwork BIM objects under the guidance of the researchers, for assistance in implementation. The research team will seek feedback from these professionals on the performance of the new BIM objects, which will be used to further direct refinement and optimisation of the upgraded BIM system, for improved applicability to real-life construction processes.

The research team will conduct a state-wide workshop program to validate and disseminate the research outcomes. A key focus of the research is research and industry training to increase the use of BIM for construction to improve project performance, with a focus on the safety of the construction. The research team will arrange dissemination workshops in Queensland cities and in the regions; this will involve training of mid- and small-size scaffolding and formwork companies in BIM, and the new objects. Their feedback will be incorporated for final refinement. The team will conduct final calibration of the new BIM objects and prepare for international dissemination of the upgraded BIM system.

EXPECTED OUTCOMES AND CONTRIBUTIONS

The research outcomes will include: a series of scaffolding and formwork BIM objects that designers and constructors can freely access for use across various IT platforms; and safe and efficient construction process methodologies integrated into the BIM objects for design and construction.

This research is significant on an Australian level, providing alignment with the national harmonisation of Workplace Health and Safety (WHS) laws and contributing technology that will support implementation of the Queensland WHS Act 2011 (WHSQ, 2011). Under existing law, a designer tends to primarily consider the usability of the building. However, the new national Act has crystallised design obligations for owners and consultants. Specifically in Part 2 Health and Safety Duties, there is requirement for a designer to consider and assess safety and constructability issues early in the project, and how the contractors will build structures safely. Subsection 22(2) indicates, 'the designer must ensure, so far as is reasonable and practicable, that the structure is designed to be without risks to the health and safety of persons.' Subsection 22(4) requires, 'the designer must give adequate information to each person who is provided with the design for the purpose of giving effect to it concerning each purpose for which the structure was designed, and any conditions necessary to ensure that the structure is without risks to health and safety when used for a designed purpose or when carrying out any activities.' This research will improve industry's capability to meet the goals of the nationally harmonised Australian WHS laws.

This research will secure long-term economic benefits by reducing construction industry accident incidence rates, improving productivity and enhancing project scheduling and efficiency. Other economic benefits will be achieved through construction planning efficiency gains. For instance, the proposed BIM formwork objects could configure the formwork systems required for the exterior wall construction of a building. The objects could be used to analyse the number of scaffolding and formwork elements required and to estimate the duration of the tasks as well as potentially material quantity and cost. This information can be used to optimise construction plans and resource procurement process.

CONCLUSION

This paper presented the research methodology developed for specific BIM objects for temporary construction works which are fully integrated; including object design, construction efficiency and safety parameters. Specifically, this project will deliver modularised scaffolding and formwork objects that will allow designers to easily incorporate them into BIM models to facilitate smarter and safer infrastructure and building construction. The 4D BIM designs and their relevant safety information could then be reviewed by field practitioners during the construction phase through resource work stations, kiosks or 3D documents that are starting to be placed at construction sites by some construction companies pushing BIM in order to deliver useful BIM information to the field.

This is a developing research initiative built on the previous works in construction safety and digital modelling conducted by the former Australian Cooperative Research Centre (CRC) for Construction Innovation and the current Sustainable Built Environment National Research Centre (SBEnrc) in Australia. This paper discussed literature review findings on the previous BIM applications for construction safety and current gaps in existing studies, proposed a preliminary methodology, and introduced expected research outcomes and their contributions to the Australian construction industry.

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